

1 What is claimed is:

2 1. A method for generating digital filters for tuning a hearing aid to  
3 enhance hearing ability comprising:

4 providing first digital data for a tolerance range for a target response  
5 curve representative of said enhanced hearing ability of sound level versus  
6 frequency;

7 providing second digital data representing an initial response curve of  
8 an initial hearing ability to be enhanced of sound level versus frequency;

9 comparing said first digital data to said second digital data and  
10 determining whether said initial response curve is within said tolerance range;  
11 and

12 if said initial response curve is not within said tolerance range,  
13 iteratively generating digital audio filters, applying said digital audio filters to  
14 said second digital data to generate third digital data for a compensated  
15 response curve, and automatically optimizing the frequency, amplitude and  
16 bandwidth of said digital audio filters until said compensated response curve  
17 is within said tolerance range or a predetermined limit on the number of digital  
18 audio filters has been reached, whichever occurs first.

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20 2. A method according to Claim 1, wherein said step of iteratively  
21 generating digital audio filters is performed by iteratively generating second  
22 order filters.

24 3. The method of Claim 1 wherein said initial response curve is an  
25 audiogram.

26  
27 4. A method for generating a set of second order filters to tune a hearing  
28 aid to enhance hearing ability comprising:

29 providing first digital data for a tolerance range for a target response  
30 curve representative of said enhanced hearing ability of sound level versus  
31 frequency;

32 providing second digital data representative of an initial response curve  
33 of an initial hearing ability to be enhanced of sound level versus frequency;

34 comparing said first digital data to said second digital data and  
35 determining whether said initial response curve is within said tolerance range;  
36 and

37 if said initial response curve is not within said tolerance range,  
38 generating a set of filters to tune said hearing aid by performing the following  
39 optimizing steps iteratively,

40 digitally processing said second digital data to determine an  $n^{\text{th}}$   
41 set of initial parameters for an  $n^{\text{th}}$  peak in said actual initial  
42 curve where said initial response curve is not within said  
43 tolerance range, including a frequency, and amplitude and a  
44 bandwidth for said peak, where  $n$  is the number of an iteration of  
45 said optimizing steps, digitally generating a compensating  $n^{\text{th}}$   
46 filter from said  $n^{\text{th}}$  set of initial parameters, applying said  $n^{\text{th}}$  filter

47 to said second digital data and modifying said  $n^{\text{th}}$  set of initial  
48 parameters to determine an  $n^{\text{th}}$  set of optimum parameters for  
49 said compensating  $n^{\text{th}}$  filter, to generate third digital data for an  
50  $n^{\text{th}}$  interim compensated response curve of sound level versus  
51 frequency, processing said third digital data to determine  
52 whether said  $n^{\text{th}}$  interim compensated response curve is within  
53 said tolerance range, if said  $n^{\text{th}}$  interim compensated response  
54 curve is not within said tolerance range, performing another  
55 iteration of said optimizing steps until said interim compensated  
56 response curve is within said tolerance range or a  
57 predetermined limit on the number of filters has been reached,  
58 whichever occurs first.

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60 5. A method of Claim 4, wherein said step of digitally generating a  
61 compensating  $n^{\text{th}}$  filter is performed by digitally generating a second order  
62 filter.

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64 6. The method of Claim 4, wherein said initial response curve is an  
65 audiogram.  
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7. A method for generating filters for tuning a hearing aid to enhance hearing ability comprising:

- providing first digital data for a tolerance range for a target response curve representative of said enhanced hearing ability of sound level versus frequency;
- providing second digital data for an initial response curve of said hearing ability to be enhanced of sound level versus frequency;
- comparing said first digital data to said second digital data and determining whether said initial response curve is within said tolerance range; and
- if said initial response curve is not within said tolerance range, generating a set of compensating filters by performing the following single filter optimizing steps iteratively,
  - digitally processing said second digital data to determine an  $n^{\text{th}}$  set of initial parameters for an  $n^{\text{th}}$  peak in said initial response curve where said initial response curve is not within said tolerance range, including a frequency, an amplitude and a bandwidth for said peak, where  $n$  is the number of an iteration of said optimizing steps,
  - digitally generating a compensating  $n^{\text{th}}$  filter from said  $n^{\text{th}}$  set of initial parameters,
  - applying said  $n^{\text{th}}$  filter to said second digital data and modifying said  $n^{\text{th}}$  set of initial parameters to determine an  $n^{\text{th}}$  set of

89 optimum parameters for said  $n^{\text{th}}$  filter, to generate third digital  
90 data for an  $n^{\text{th}}$  interim compensated response curve of sound  
91 level versus frequency;  
92 if  $n > 1$ , performing the following joint filter optimizing steps iteratively and  
93 cyclically,  
94 generating fourth digital data for interim computed response curves  
95 in which for each joint filter optimizing iteration one of said  $n$  filters  
96 is absent, and then performing said single filter optimization steps  
97 utilizing said fourth digital data to generate fifth digital data for an  
98 updated interim response curve,  
99 digitally processing said fifth digital data to determine whether the  
100 most recent of said joint filter optimizing iterations has resulted in a  
101 change in said updated interim response curve greater than a  
102 predetermined amount of change, and if so continuing to perform  
103 said joint filter optimizing steps;  
104 processing said fifth digital data to determine whether said  $n^{\text{th}}$   
105 interim compensated response curve is within said tolerance range,  
106 and if not,  
107 performing another iteration of the foregoing steps until said  
108 interim compensated response curve is within said tolerance  
109 range or a predetermined limit on the number of filters has  
110 been reached, whichever occurs first,  
111 but if so, ceasing performance of further iterations.

1 8. A method according to Claim 7, wherein said step of digitally  
2 generating a compensating  $n^{\text{th}}$  filter is performed by digitally generating a  
3 second-order filter.

4  
5 9. The method of Claim 8 wherein said initial response curve is an  
6 audiogram.

1 10. A method for generating filters for tuning a hearing aid to enhance  
2 hearing ability of an individual comprising:  
3 fitting said hearing aid to said individual;  
4 connecting said hearing aid to a source of audio digital signals;  
5 providing said individual with a device to generate indication signals at  
6 will;  
7 generating and providing a first series of audio digital signals to said  
8 hearing aid, each signal in said first series of signals having a selected  
9 frequency and multiple power levels;  
10 receiving said indication signal during said generation of a signal of a  
11 selected frequency indicative of said individual hearing said selected  
12 frequency;  
13 providing a digital audio processing unit in said hearing aid for  
14 processing received audio digital signals and providing processed audio

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15 digital data, including applying digital audio filters for tuning said hearing  
16 aid characterized by coefficients in algorithms applied to said received  
17 audio digital signals to effect said digital audio filters;  
18 providing a digital computer connected to receive said first series of  
19 audio digital signals and said indication signals to generate digital data  
20 representative of said individual's hearing ability using said hearing aid  
21 without filters determined from said first series of signals, said computer  
22 programmed to determine said coefficients for digital filters for tuning  
23 said hearing aid and providing said coefficients to said digital audio  
24 processing unit in said hearing aid.

1 11. A method according to Claim 10, wherein said digital computer is  
2 programmed to determine said coefficients by  
3 providing second digital data for a tolerance range for a target response  
4 curve ability of representative of said individual's enhanced hearing  
5 ability of sound level versus frequency;  
6 providing first digital data representative of an initial response curve of  
7 said individual's hearing ability of sound level versus frequency;  
8 comparing said second digital data to said first digital data and  
9 determining whether said response curve is within said tolerance range;  
10 and  
11 if said response curve is not within said tolerance range,

iteratively generating coefficients for digital audio filters, applying digital audio filters determined by said coefficients to said first digital data to generate third digital data for a compensated response curve, and automatically optimizing said coefficients by optimizing the frequency, amplitude and bandwidth of said digital audio filters until said compensated response curve is within said tolerance range or a predetermined limit on the number of digital audio filters has been reached, whichever occurs first.

12. The method of Claim 11 wherein said computer receives said first series of signals and indication signals generated by said device to generate said first digital date.

13. The method of Claim 11 wherein said first digital data is an audiogram.

14. An apparatus for generating filters for tuning a hearing aid for use by an individual, comprising:

- a source of first audio digital data;
- a digital audio processing unit in said hearing aid for processing said first audio digital data and providing processed audio digital data to said individual, including applying digital audio filters for tuning said hearing

an individual, comprising:

a source of first audio digital data;

a digital audio processing unit in said hearing aid for processing said first

audio digital data and providing processed audio digital data to said

individual, including applying digital audio filters for tuning said hearing



aid characterized by coefficients in algorithms applied to said first audio digital data to effect said digital audio filters;  
a device for generating indication signals indicative of said individual receiving said first audio digital data; and  
a digital computer connected to receive said first audio digital data and said indication signals, said digital computer programmed to determine said coefficients for digital filters for tuning said hearing aid and provide said coefficients to said digital audio processing unit.

15. An apparatus according to Claim 14, wherein said digital computer is programmed to generate second digital data representative of said individual hearing ability when using said hearing aid without filters determined from said first audio digital data and said indication signals and to determine said coefficients by

providing third digital data for a tolerance range for a target response curve of enhanced hearing of sound level versus frequency;

providing said second digital data, wherein said second digital data represents an initial response curve of hearing ability of sound level versus frequency;

comparing said third digital data to said second digital data and determining whether said initial response curve is within said tolerance range; and

if said initial response curve is not within said tolerance range,



iteratively generating digital audio filters to compensate said initial response curve,

applying said digital audio filters to digital signals representative of received sound to generate third digital data, converting said third digital data to an analog signal and providing said analog signal to a speaker in said hearing aid,

generating fourth digital data representative of an enhanced response curve of hearing ability of sound level versus frequency;

comparing said first digital data to said fourth digital data and determining whether said enhanced response curve is within said tolerance range; and

automatically optimizing the frequency, amplitude and bandwidth of said digital audio filters until said enhanced response curve is within said tolerance range or a predetermined limit on the number of digital audio filters has been reached, whichever occurs first.

17. A method according to Claim 16, wherein said step of iteratively generating digital audio filters is performed by iteratively generating second-order filters.

18. The method of Claim 16 wherein said initial response curve is an audiogram.

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8 19. The method of Claim 18 wherein said enhanced response curve is an  
9 audiogram.

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11 20. A method for generating total log-integral metric digital data for  
12 characterizing the perceived performance of a hearing aid, comprising the  
13 steps of:

14 providing first digital data for N samples for a desired response curve of  
15 acceptable hearing ability of sound level versus frequency;

16 providing second digital data representing N samples for an initial  
17 response curve of sound level versus frequency; and

18 generating total log-integral metric data according to the formula:

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$$M = \sum_{i=1}^{N-1} \log_{10} \left( \frac{f_{i+1}}{f_1} \right) \left[ \frac{|S(f_1)_{dB} - D(f_1)_{dB}| + |S(f_{i+1})_{dB} - D(f_{i+1})_{dB}|}{2} \right]$$

where:

M is the total log-integral metric,

f is the frequency,

D is the first digital data,

S is the second digital data, and

N is the number of samples of first digital data and of second  
digital data.